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Developing an E-commerce Trust Model in Crowdfunding by Integrating Blockchain and Edge Computing Using Fuzzy Technique

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Abstract

This study investigates the integration of blockchain and edge computing technologies to enhance E-commerce trust in crowdfunding platforms using fuzzy techniques. The research focuses on five key dimensions of trust: Security, Transparency, Efficiency, Social Trust, and Technical Capabilities. By applying Multi-Criteria Decision-Making (MCDM) methodologies, including FUCOM, IDOCRIW, and F-CoCoSo, the study evaluates solutions designed to address trust-related challenges in crowdfunding. A comprehensive case study of Iranian crowdfunding platforms was conducted to empirically validate these solutions using fuzzy logic and advanced MCDM techniques. The study's key innovation lies in the development of a novel trust framework that combines blockchain and edge computing technologies with advanced fuzzy-based MCDM methods. This framework uniquely addresses the challenges of transparency, fraud prevention, and real-time auditing in crowdfunding ecosystems while providing a scalable and decentralized approach to enhancing trust. The findings highlight three primary solutions for reinforcing trust: S4 (Implementing a Blockchain-Based Auditing and Monitoring System), S2 (Implementing a Decentralized User Verification System), and S6 (Enhanced Security with Blockchain and Edge Computing Synergy). These solutions provide significant improvements in real-time auditing, user verification, and system security, ensuring enhanced transparency, fraud prevention, and performance. Additionally, the study incorporates sensitivity analysis using techniques such as F-MARCOS, F-SECA, F-KEMIRA, and F-MABAC to evaluate the robustness of the findings. The analysis demonstrates that the proposed solutions remain stable across varying decision-making scenarios, confirming their reliability and effectiveness. This research advances the theoretical understanding of trust in E-commerce by integrating blockchain and edge computing, offering a scalable, efficient, and secure model for crowdfunding platforms. The results suggest that these solutions are crucial for fostering a more transparent, reliable, and trustworthy digital financial environment, contributing to the sustainable growth of the crowdfunding industry. The study's implications extend to both academic theory and practical applications, providing a roadmap for future developments in digital trust frameworks.

Keywords: Blockchain, Edge computing, Crowdfunding, E-commerce trust, Fuzzy.

1 | Introduction

Crowdfunding represents a novel, technology-driven innovation that is reshaping the landscape of capital markets. Internet-based applications, especially those associated with Web 2.0, have profoundly influenced various sectors of society, including education, business, and healthcare [1]. Crowdfunding has emerged recently, driven both by increasing market demand for alternative financing solutions and by legislative efforts

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to integrate this innovative financing method into existing regulatory frameworks [2]. In crowdfunding settings, trust is paramount due to the considerable information asymmetry between entrepreneurs and potential investors—a gap that is even more pronounced than in traditional financing methods [3], [4]. This disparity directly influences how comfortable investors feel about the way entrepreneurs allocate and use funds [3], [5]. Moreover, trust plays a critical role in shaping investment decisions, serving as a key factor in determining supporters' willingness to participate in crowdfunding projects [6], [7]. This importance spans various crowdfunding models, whether they are equity-based or donation-based [7]. Trust is primarily established through effective information sharing. Crowdfunding projects that offer detailed, transparent descriptions and maintain high levels of informativeness can significantly improve their success rates. This is especially crucial given that potential funders typically have limited information and cognitive resources to evaluate project viability [8]. In contrast, the absence of sufficient trust can lead to reduced investor participation, an increase in fraudulent activities, and ultimately, the failure of crowdfunding initiatives [6]. Such outcomes underscore the essential role of trust in entrepreneurial finance and its direct impact on the success of crowdfunding endeavors [3].

In the crowdfunding environment, several significant challenges related to trust arise due to its inherently online nature and unique characteristics. One major concern is the high level of uncertainty present in digital transactions, where trust plays a critical role in decision-making processes. This uncertainty is particularly problematic because investors are often unable to fully evaluate products or services before making investment decisions [9]. Additionally, the digital marketplace context introduces challenges such as information asymmetry and increased transaction risks [10]. These issues are exacerbated by the absence of traditional professional project screening mechanisms in crowdfunding, rendering the system more vulnerable to fraud and misuse of investors' funds [9]. Moreover, trust concerns in crowdfunding extend beyond individual transactions to influence broader marketplace dynamics. The effectiveness of institutional mechanisms and reliable third-party services is crucial for establishing trust and facilitating successful transactions [11]. Without these critical trust-building elements, the perceived risks can significantly deter potential investors from participating in crowdfunding initiatives. These challenges are further complicated by the cross-cultural nature of online crowdfunding platforms, where differing cultural expectations and trust norms affect how investors perceive trustworthiness [12]. Despite wide variations in legal frameworks, mitigating risk and building trust remain perennial concerns for the market, forming the foundation of initiatives aimed at enhancing Crowdfunding Intention (CI) and behavior [13]. Previous trust models were expanded upon by defining cognitive trust as a set of beliefs and emotional trust as an attitudinal orientation. The relationship between these two forms of trust was empirically measured and analyzed [14].

Traditional crowdfunding platforms rely on intermediaries such as payment gateways and escrow services, which typically charge fees ranging from 3% to 5%, thereby significantly diminishing the funds that creators ultimately receive. In addition, these platforms often suffer from a lack of transparency—contributors usually do not have clear insight into how funds are allocated, a shortcoming that discourages repeated investments. Compliance with regulations, particularly those related to Anti-Money Laundering (AML) and Know-Your-Customer (KYC) requirements, further contributes to operational delays and increased costs. Moreover, the centralized nature of these infrastructures limits scalability, restricting the ability to support large campaigns and engage with a global audience [15]. Blockchain technology offers a robust solution to these inefficiencies through its decentralized, transparent, and secure framework. By eliminating intermediaries, blockchain significantly reduces transaction costs and leverages immutable ledgers to enhance trust and accountability. Furthermore, blockchain's inherent security features help mitigate fraud risks by enabling investors to monitor projects in real time [16].

As edge computing continues to expand its adoption, its impact on crowdfunding platforms is becoming ever more critical. Global expenditures on edge computing are forecast to reach $317 billion by 2026, indicating that this technology will play an essential role in improving both the performance and efficiency of crowdfunding platforms. Furthermore, by enhancing data processing capabilities and reducing latency, edge computing enables real-time interactions and significantly improves user experiences—factors that are vital

for building trust among potential backers [17]. Trust is a central element within the crowdfunding ecosystem, shaped by factors such as transparency, accountability, and the quality of communication between project creators and backers. High levels of transparency—characterized by the comprehensive disclosure of project details, regular updates, and candid acknowledgment of challenges—help cultivate a sense of security among potential investors. Nevertheless, trust issues persist; variations in how campaign risks are presented can lead to differing perceptions among backers, creating complex dynamics that may either encourage or discourage investment [18]. Edge computing offers a promising avenue for mitigating these trust-related challenges by addressing key security and privacy concerns. Its decentralized architecture enhances data processing speeds and reduces the vulnerabilities associated with centralized systems, thereby facilitating the secure handling of sensitive personal and financial information. Moreover, cutting-edge edge computing technologies, including secure multiparty computation and federated learning, further reinforce user trust by ensuring data privacy and enabling real-time engagement and feedback—factors that are essential for sustaining trust in crowdfunding relationships [17].

Despite these notable advantages, significant challenges remain in integrating edge computing into crowdfunding platforms. Persistent security risks, the complexity of maintaining robust protection across numerous devices, and the difficulty of effectively managing trust relationships continue to pose major obstacles. Consequently, ongoing research and the development of innovative strategies are essential to fully harness the potential of edge computing for enhancing trust, thereby paving the way for more secure and successful fundraising initiatives in the future. Although blockchain and edge computing have each been recognized for their potential to improve trust in e-commerce and crowdfunding environments, comprehensive research exploring the synergy between these technologies is still lacking. Most existing studies examine blockchain or edge computing in isolation without addressing how their integration might resolve the multifaceted trust issues inherent in crowdfunding. This gap in the literature presents an opportunity to develop a combined model that leverages the strengths of both technologies, ultimately establishing a holistic approach to trust management in crowdfunding platforms.

2 | Literature

2.1 | Trust in Crowdfunding

The trust model in crowdfunding encompasses the principles and mechanisms that shape the interactions between project creators and backers, often established without any prior personal connection. Trust is a critical element in this unconventional financing approach, as it greatly impacts the willingness of potential investors to support projects that may lack collateral or proven credibility. As the crowdfunding industry continues to expand, gaining insights into how trust operates is essential not only for the success of individual campaigns but also for maintaining the long-term health of the crowdfunding ecosystem [19].

Several factors contribute to building trust within crowdfunding platforms, including the perceived reputation of project creators, the quality of services offered by platforms, clear and transparent communication, and adherence to regulatory standards. Studies show that backers are more inclined to support projects led by creators with solid reputations and positive feedback from peers, as these aspects increase the perceived trustworthiness of the project. Moreover, regular and honest communication from creators, coupled with reliable platform performance, plays a vital role in cultivating investor confidence. Nevertheless, crowdfunding faces significant trust-related challenges. Issues like fraud, false representation, and lack of transparency can severely undermine investor confidence. When creators present inaccurate information or omit essential project details, it can tarnish the platform's reputation and diminish user trust. Additionally, in regions where regulatory frameworks are inconsistent or absent, backers may hesitate to invest due to concerns about the security of their contributions [20]. Looking forward, the integration of technologies like blockchain and the development of stronger regulatory measures are expected to significantly influence trust models in crowdfunding. As platforms evolve to meet increasing demands for transparency and security, their ability to establish and sustain trust will be pivotal in attracting backers and ensuring the success of fundraising

campaigns. For both crowdfunding platforms and project creators, understanding and adapting to the changing dynamics of trust will be key to navigating the complex crowdfunding landscape effectively [21].

Comprehensive research and practical evaluations are essential to fully grasp how blockchain and edge computing can be seamlessly integrated to create robust and sustainable trust models for crowdfunding platforms. Trust stands as a cornerstone in the success of these platforms, directly affecting user engagement and the overall credibility of the platform. By addressing trust-related challenges through innovative technologies such as blockchain and edge computing, crowdfunding can continue to evolve and solidify its position as a reliable and effective financing mechanism.

2.2 | Blockchain and Crowdfunding

Blockchain technology functions as a decentralized ledger that connects a network of nodes in an efficient, secure, and tamper-proof manner. Its integration into crowdfunding can enhance the system by making it more reliable, transparent, and trustworthy while reducing costs and increasing convenience. In this model, rather than merely acting as an intermediary, the crowdfunding platform would primarily supply the underlying technology and introduce its cryptocurrency as the medium of transaction and exchange. Fundraisers would generate their digital currency, and notifications about projects would be disseminated across the network. Investors could purchase these tokens to acquire a stake in a project and later have the option to withdraw by selling their tokens—thus relinquishing their share—or transferring them to another project. Ultimately, blockchain technology can further refine this innovative fundraising method by significantly improving its reliability and transparency [22].

The blockchain serves as an open, decentralized ledger and database, providing innovative methods for securing and transferring data via peer-to-peer networks, characterized by permanent, transparent, and unchangeable transaction records [23]. Scalability and latency remain significant challenges for data storage and management in blockchain systems [24]. Blockchain technology can also create smart contracts that automate the delivery process [25]. Its widespread adoption has been fueled by media coverage that highlights its various applications [26]. Organizations and investors have embraced blockchain due to its potential to deliver enhanced efficiency, transparency, security, and reduced transaction costs [27]. In terms of transaction cost economics, blockchain improves trust mechanisms, eliminates the need for third-party intermediaries, and provides verifiable transaction records, thus reducing costs [28]. Blockchain's traceability enables users to monitor the entire transaction process, establishing a foundation for 'trustless' economic exchanges [29]. Furthermore, the technology strengthens financial forensics and aids in combating financial crimes, such as money laundering [30], [31], making it highly beneficial for financial institutions [32].

The integration of blockchain technology into crowdfunding has garnered significant attention in recent years. Blockchain, known for its decentralized, transparent, and immutable nature, offers a promising solution to several challenges in traditional crowdfunding models, particularly concerning trust, security, and efficiency [33]. This literature review explores the role of blockchain in crowdfunding, highlighting how it addresses trust issues, enhances security, and provides new opportunities for innovation in the crowdfunding ecosystem. Trust is a critical factor in the success of crowdfunding platforms. Traditional crowdfunding relies heavily on intermediaries (platforms) to facilitate transactions and ensure the credibility of projects. However, this model is not without its challenges, including risks of fraud, mismanagement of funds, and lack of transparency [34]. Blockchain technology, with its decentralized ledger system, offers a way to mitigate these risks by eliminating the need for a central authority and enabling direct, transparent interactions between project creators and backers [35]. Several studies have highlighted the potential of blockchain to enhance trust in crowdfunding. For example, Chen et al. [7] discussed how blockchain can provide immutable records of all transactions, ensuring that funds are used as intended and that project milestones are transparently tracked. This transparency reduces the information asymmetry that often plagues traditional crowdfunding platforms, where backers may have limited visibility into how their contributions are being used. Moreover, De Filippi and Wright [36] examined how smart contracts—self-executing contracts with the terms of the agreement

directly written into code—can be utilized in crowdfunding to automatically enforce agreements between backers and creators. This automation not only reduces the potential for fraud but also streamlines the process, making it more efficient and less prone to human error [36]. Security is another area where blockchain technology can significantly impact crowdfunding. Traditional crowdfunding platforms often require backers to provide personal and financial information, which can be vulnerable to breaches and misuse. Blockchain, by contrast, offers a more secure alternative through its use of cryptographic techniques to protect data and ensure that it is only accessible to authorized parties [33].

Furthermore, Zheng et al. [37] explored how blockchain can prevent double-spending, a critical issue in digital transactions where the same funds could be spent more than once. By using a consensus mechanism, blockchain ensures that all transactions are verified and recorded across the network, making it virtually impossible to alter transaction histories or duplicate funds. Blockchain has also paved the way for new crowdfunding models, such as Initial Coin Offerings (ICOs) and Security Token Offerings (STOs). These models leverage blockchain technology to issue digital tokens that represent ownership or other rights in a project or company, which backers can purchase during the crowdfunding campaign [38]. ICOs, in particular, have gained popularity as a means of raising funds for blockchain-based projects. They allow project creators to bypass traditional fundraising methods and directly reach a global pool of investors. However, the ICO model is not without its challenges, including regulatory uncertainty and the potential for fraudulent activities [39]. STOs, on the other hand, are designed to address some of these issues by adhering to existing securities regulations and providing greater protection for investors [40]. The work of Fisch [41] provides a comprehensive analysis of ICOs and their impact on crowdfunding, noting that while they offer significant opportunities for innovation and growth, they also require careful regulation to protect investors and ensure the long-term sustainability of the market. Fisch's study [41] suggests that the success of blockchain-based crowdfunding models will depend largely on the development of clear regulatory frameworks that balance innovation with investor protection. Several key elements—such as social purpose, transparency, reliability, and trustworthiness—are essential for the success of crowdfunding platforms. Despite growing interest in the potential benefits of blockchain technology for enhancing crowdfunding platforms due to its distinctive capabilities, limited research has examined the connection between blockchain's unique features and the crucial factors required for crowdfunding platforms to thrive [42].

2.3 | Edge Computing and Crowdfunding

In today's dynamic and highly competitive global markets, organizations encounter various obstacles that threaten their sustainability and expansion [43]. Edge computing refers to the delivery of computing services over the Internet, including servers, databases, storage, software, networking, intelligence, and analytics [44]. Edge computing has transformed data storage and processing, but it faces challenges when dealing with latency-sensitive applications [45]. Most businesses rely heavily on cloud computing and Artificial Intelligence (AI) to secure and manage their resources. As automation becomes a priority for business owners, the demand for Cloud Computing and AI technologies has risen significantly [46]. The rapid growth of crowdfunding as an alternative to traditional financing has led to increasing interest in integrating advanced technologies to enhance platform performance, security, and user experience. One such technology is edge computing, which processes data closer to the source, reducing latency and improving the responsiveness of online platforms [47]. One of the most significant challenges traditional cloud-based crowdfunding platforms face is latency, the delay between a user's action and the platform's response [48]. High latency can lead to poor user experience, particularly in situations where real-time data processing is crucial, such as in live crowdfunding campaigns or dynamic pricing models [49]. Edge computing addresses this issue by bringing data processing closer to the user, thereby reducing the time it takes to execute transactions and update information [47]. Edge computing offers a decentralized approach, distributing data processing across multiple edge nodes rather than relying on a single central server [48]. Research by Abbas et al. [50] highlights how edge computing can enhance the scalability of crowdfunding platforms. By offloading data processing to edge nodes, these platforms can handle a more significant number of simultaneous users and transactions without sacrificing

performance. This decentralized approach also reduces the load on central servers, further improving the platform's ability to scale efficiently [50]. Moreover, Wang et al. [48] explored how edge computing could be integrated with existing cloud infrastructures to create a hybrid model that balances the benefits of both approaches. In this model, less critical data is processed at the edge, while more complex tasks are handled by the cloud. This hybrid approach allows crowdfunding platforms to scale more effectively while maintaining high performance and reliability [48]. Security is a paramount concern in crowdfunding, where large amounts of sensitive user data and financial transactions are involved. Traditional cloud-based platforms are vulnerable to various security threats, including data breaches, Distributed Denial of Service (DDoS) attacks, and unauthorized access [46]. Edge computing offers enhanced security features by distributing data processing and storage across multiple nodes, making it more difficult for attackers to compromise the entire system [47]. Edge computing can also improve data privacy by enabling localized data processing. Sensitive information can be processed and stored at the edge, closer to the user, reducing the need to transmit data over potentially insecure networks [49]. This localized processing reduces the risk of data interception and unauthorized access, as demonstrated in a study by Roman et al. [51], which found that edge computing could reduce the attack surface of crowdfunding platforms by up to 30% [50]. Additionally, edge computing allows for more robust and distributed security protocols, such as blockchain-based security frameworks. These frameworks can be implemented at the edge to ensure that all transactions and data exchanges are secure and tamper-proof. This combination of edge computing and blockchain technology provides a comprehensive security solution that addresses many of the vulnerabilities present in traditional cloud-based crowdfunding platforms. User experience is a critical factor in the success of crowdfunding platforms. A positive user experience encourages participation and increases the likelihood of successful campaigns [34]. Edge computing can enhance user experience by providing faster, more responsive platforms that can handle high volumes of traffic without slowing down or crashing. A study by Shi et al. found that crowdfunding platforms utilizing edge computing could deliver content and process transactions more quickly, resulting in a more seamless user experience. This improvement is particularly important for mobile users, who may experience inconsistent performance due to varying network conditions. By processing data closer to the user, edge computing ensures that platform performance remains consistent across different devices and locations [47]. Furthermore, edge computing supports real-time data analytics, enabling platforms to provide users with up-to-date information on campaign progress, funding levels, and user interactions. This real-time feedback is essential for engaging users and encouraging continued participation in crowdfunding campaigns. It also allows project creators to adjust their strategies based on real-time data, improving their chances of success. While edge computing offers significant advantages for crowdfunding platforms, several challenges remain. One of the primary concerns is the complexity of managing a distributed edge network, particularly regarding data synchronization and consistency [46]. Ensuring that all edge nodes are synchronized and that data is consistent across the network requires sophisticated algorithms and robust infrastructure, which can be costly and difficult to implement. Another challenge is the potential for increased latency in scenarios where data must be transmitted between multiple edge nodes before reaching its final destination [48]. While edge computing reduces latency for localized processing, it can introduce delays when data needs to be aggregated or analyzed across different nodes. Addressing this challenge requires careful planning and optimization of the edge network architecture. Despite these challenges, the opportunities for integrating edge computing into crowdfunding platforms are significant. The technology offers the potential to create more responsive, scalable, and secure platforms that can handle the growing demands of the crowdfunding ecosystem [47]. As research in this area continues to evolve, edge computing is likely to play an increasingly important role in the future of crowdfunding, offering new models and approaches that enhance both platform performance and user experience.

3 | Methodology

This study explores trust indicators in e-commerce within crowdfunding by reviewing relevant literature and consulting experts. Following this, it identifies solutions for enhancing e-commerce trust in crowdfunding through the implementation of blockchain and edge computing. A comprehensive decision-making

framework, utilizing FUCOM, IDOCRIW, and F-CoCoSo methods, is introduced to assess the proposed solutions. Subsequently, sensitivity analysis is conducted, employing F-SECA, F-KEMIRA, F-MABAC, and F-MARCOS techniques to evaluate the robustness of the findings, ensuring their accuracy and reliability. Based on these results, both practical and academic recommendations are offered for integrating blockchain and edge computing to reinforce trust in crowdfunding. The research process is illustrated in *Fig. 1*.

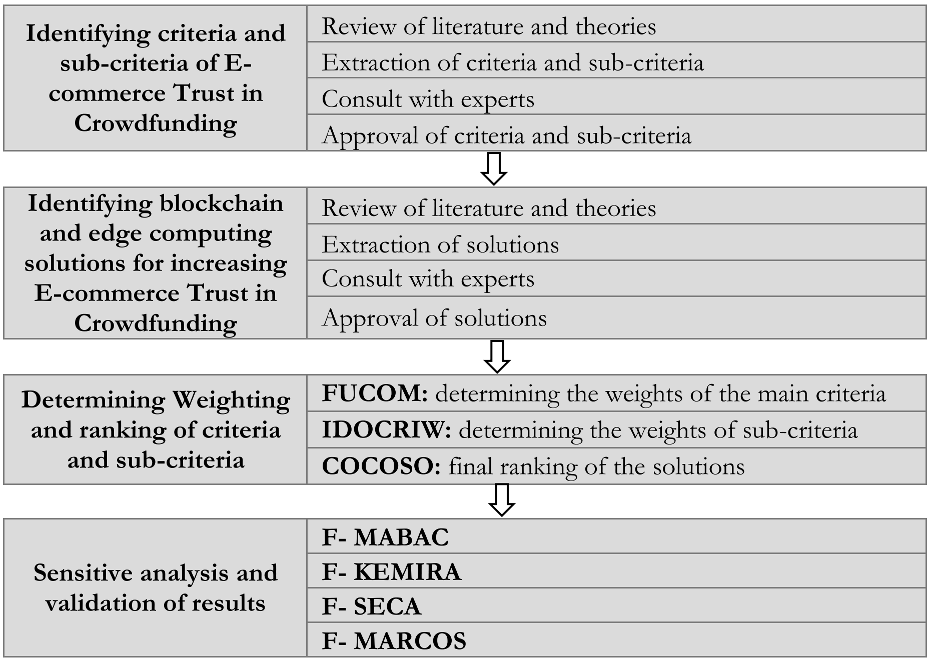

Fig. 1. The steps of the research.

3.1 | Fuzzy FUCOM (F-FUCOM)

In the field of operations research, numerous scholars and researchers integrate fuzzy variables into their models to address the inherent uncertainty of real-world problems [52]. With the rapid progress of science and technology, decision-making in business and industry has become increasingly intricate and challenging. Consequently, decision-making refers to the process of identifying, assessing, and selecting among various alternatives. Fuzzy ranking encompasses a set of methods designed to address ranking problems by incorporating flexible, imprecise, or uncertain constraints and objectives using fuzzy sets [53]. FUCOM, a Multi-Criteria Decision-Making (MCDM) method introduced by Pamučar et al. [54], is designed to determine the final weights of criteria through the subjective evaluations of decision-makers. It utilizes pairwise comparisons among the decision criteria to establish these weights [55]. In a typical MCDM problem, there are n evaluation criteria, represented as w_j, where $w_j, j = 1,2, \dots, n$ and their respective weight coefficients need to be established. Subjective models for determining weights, which rely on pairwise comparisons of criteria, require decision-makers to assess the influence of criterion i on criterion j. This degree of influence is expressed as a comparison value a_{ij}. Since these comparison values are not derived from precise measurements but are based on subjective judgments, it is natural to expect some level of uncertainty, which is often represented using fuzzy numbers. In the application of fuzzy numbers within MCDM models, linguistic scales are commonly employed. In this context, the paper utilizes a fuzzy linguistic scale, described by triangular fuzzy numbers, to express expert preferences in the F-FUCOM method (*Table 1*). Since the model is multicriteria, it is important to note that it can also be applied to determine the weight coefficients of alternatives, leading to the final ranking and selection of the best option among the observed alternatives.

Table 1. Fuzzy linguistic scale.

Linguistic Terms	Membership Function
Equally important (EI)	(1,1,1)
Weakly important (WI)	(2/3,1,3/2)
Fairly Important (FI)	(3/2,2,5/2)
Very important (VI)	(5/2,3,7/2)
Absolutely important (AI)	(7/2,4,9/2)

Building on the foundational principles of FUCOM, the traditional model has been extended into a fuzzy environment, leading to the development of the F-FUCOM algorithm, which is outlined in four steps:

Step 1. Define the decision criteria.

The first step in multicriteria models for evaluating alternatives is to establish a set of evaluation criteria. As explained earlier, suppose there are n criteria, represented by $C = \{C_1, C_2, \dots, C_n\}$.

Step 2. Rank the decision criteria.

Experts rank the criteria according to their perceived importance. The criterion expected to have the highest weight is ranked first, followed by those with progressively lower significance. The criterion anticipated to have the lowest weight is ranked last. This step results in a ranking of criteria based on their anticipated impact on decision-making in the MCDM model:

$$C_j(1) > C_j(2) > \cdots > C_j(k), \tag{1}$$

where k represents the rank of the criterion. If two or more criteria share the same importance, an equality sign is used between them instead of ">".

Step 3. Compare criteria using TFNs.

The criteria are compared using fuzzy linguistic terms from a predefined scale (*Table 1*). The comparison is made relative to the most significant criterion (the first-ranked one). From these comparisons, the fuzzy significance $\left(\varpi_{C_{j(k)}}\right)$ for each ranked criterion is calculated. Since the most important criterion is compared to itself $\left(\varpi C_{j(1)} = EI\right), n-1$, there will be comparisons for the remaining criteria. Using the defined importance of the criteria, the fuzzy comparative significance $\varphi_K/(k+1)$ is determined by applying *Eq. (2)*.

$$\varphi_{k/(k+1)} = \frac{\varpi_{C_{j(k+1)}}}{\varpi_{C_{j(k)}}} = \frac{\left(\varpi^l_{C_{j(k+1)}}, \varpi^m_{C_{j(k+1)}}, \varpi^u_{C_{j(k+1)}}\right)}{\left(\varpi^l_{C_{j(k)}}, \varpi^m_{C_{j(k)}}, \varpi^u_{C_{j(k)}}\right)}. \tag{2}$$

As a result, a fuzzy vector representing the relative importance of the evaluation criteria is derived using the equation:

$$\Phi = \varphi_{1/2}, \varphi_{2/3}, \dots \varphi_{\frac{k}{k+1}}, \tag{3}$$

where $\varphi_{k/(k+1)}$ represents the significance that the criterion of $C_{j(k)}$ rank has in relation to the criterion of $C_{j(k+1)}$ rank.

Step 4. Calculate the optimal fuzzy weights.

In the fourth step, the final values of the fuzzy weight coefficients of criteria $(w_1, w_2, \dots w_n)^T$ are calculated. The final values of weight coefficients should satisfy two conditions:

Condition 1: The ratio of weight coefficients of the observed criteria ($C_{j(k)}$ and $C_{j(k+1)}$ should be equal to their comparative significance $\varphi_{k/(k+1)}$ defined in *Step 2*, i.e., that it fulfills the condition:

$$\frac{w_k}{w_{k+1}} = \varphi_{k/(k+1)}. \tag{4}$$

Condition 2: In addition to the condition defined by *Eq. (5)*, the final values of weight coefficients should satisfy transitivity, i.e., that $\varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)} = \varphi_{k/(k+2)}$ i.e. that $\frac{w_k}{w_{k+1}} \otimes \frac{w_{k+1}}{w_{k+2}} = \frac{w_k}{w_{k+2}}$. Thus, another condition that needs to be satisfied by the final values of weight coefficients is obtained:

$$\frac{w_k}{w_{k+2}} = \varphi_{k/(k+1)} \otimes \varphi_{\frac{k+1}{k+2}}. \tag{5}$$

Minimum DMC, i.e. $\chi = 0$, is satisfied only if the transitivity among weight coefficients are completely satisfied. Then, it can be said that $\frac{w_k}{w_{k+1}} = \varphi_{k/(k+1)} = 0$ and $\frac{w_k}{w_{k+2}} - \varphi_{\frac{k}{k+1}} \otimes \varphi_{\frac{k+1}{k+2}} = 0$. For such obtained values of weight coefficients, DMC is $\chi = 0$. In order to satisfy these conditions, it is necessary to determine the values of the weight coefficients of criteria $(w_1, w_2, \dots w_n)^T$ that satisfy the condition that $\left|\frac{w_k}{w_{k+1}} - \varphi_{k/(k+1)}\right| \leq \chi$ and $\left|\frac{w_k}{w_{k+2}} - \varphi_{\frac{k}{k+1}} \otimes \varphi_{\frac{k+1}{k+2}}\right| \leq \chi$ with the minimization of value χ.

Based on the settings defined, the final nonlinear model for determining the optimal fuzzy values of the weight coefficients of the evaluation criteria can be set $(w_1, w_2, \dots w_n)^T$.

$$\begin{gathered} \min \chi \\ \text{s.t.} \end{gathered}$$
$$\begin{cases} \left|\frac{w_k}{w_{k+1}} - \varphi_{k/(k+1)}\right| \leq \chi, & \text{for all } j, \\ \left|\frac{w_k}{w_{k+2}} - \varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)}\right| \leq \chi, & \text{for all } j, \\ \sum_{j=1}^{n} w_j = 1, & \text{for all } j, \\ w_j^l \leq w_j^m \leq w_j^u & \\ w_j^l \geq 0, \ \text{for all } j, & \\ j = 1,2,\dots,n, & \end{cases} \tag{6}$$

where $w_j = \left(w_j^l, w_j^m, w_j^u\right)$ and $\varphi_{k/(k+1)} = \left(\varphi_{k/(k+1)}^l, \varphi_{k/(k+1)}^m, \varphi_{k/(k+1)}^u\right)$.

In order to achieve the highest consistency, it is necessary to satisfy the condition that $\frac{w_k}{w_{k+1}} - \varphi_{\frac{k}{k+1}} = 0$ and $\frac{w_k}{w_{k+2}} - \varphi_{\frac{k}{k+1}} \otimes \varphi_{\frac{k+1}{k+2}} = 0$. Thereby, the model given by *Eq. (6)* can be transformed into a fuzzy linear model, *Eq. (7)*. The optimal fuzzy values of weight coefficients are obtained $(w_1, w_2, \dots w_n)^T$, if it is solved.

$$\begin{gathered} \min \chi \\ \text{s.t.} \end{gathered}$$
$$\begin{cases} \left|w_k - w_{k+1} \otimes \varphi_{k/(k+1)}\right| \leq \chi, \ \text{for all } j, & \\ \left|w_k - w_{k+2} \otimes \varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)}\right| \leq \chi, & \text{for all } j, \\ \sum_{j=1}^{n} w_j = 1, \ \text{for all } j, & \\ w_j^l \leq w_j^m \leq w_j^u, & \\ w_j^l \geq 0, \ \text{for all } j, & \\ j = 1,2,\dots,n, & \end{cases} \tag{7}$$

where $w_j = \left(w_j^l, w_j^m, w_j^u\right)$ and $\varphi_{k/(k+1)} = \left(\varphi_{k/(k+1)}^l, \varphi_{k/(k+1)}^m, \varphi_{k/(k+1)}^u\right)$.

3.2 | IDOCRIW Algorithm

The Integrated Determination of Objective Criteria Weights (IDOCRIW) algorithm, developed by Zavadskas et al. [56] combines the entropy method with the Criterion Impact LOSs (CILOS) approach. This algorithm

is primarily applied in multivariable decision-making scenarios. When a dataset D includes n samples (or alternatives) and m variables (or features or criteria) are measured for each sample, this multidimensional dataset can be described as follows:

$$D = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{n1} & x_{2n} & \cdots & x_{nn} \end{bmatrix}. \quad (8)$$

The process of the IDOCRIW algorithm involves the following steps [56]:

Step 1. Normalizing the data matrix.

In order to remove the influence of variable measurement units, the initial step is to normalize the data matrix using the following equation:

$$\tilde{x}_{ij} = \frac{x_{ij}}{\sum_{i=1}^{n} x_{ij}}, i = 1,2,\ldots,n, j = 1,2,\ldots,m, \quad (9)$$

Step 2. Calculating the entropy for each variable or criterion.

The entropy is determined using the following equation:

$$E_j = \frac{1}{Ln(n)} \sum_{i=1}^{n} \tilde{x}_{ij} Ln(\tilde{x}_{ij}), j = 1, 2, \ldots, m, 0 \leq E_j \leq 1. \quad (10)$$

Step 3. Calculating the uncertainty or degree of deviation for each variable using the following formula:

$$d_j = 1 - E_j, j = 1,2,\ldots,m. \quad (11)$$

Step 4. Calculating the weight of each variable.

The weight of each variable is determined using the entropy method, applied through the following equation:

$$w_j = \frac{d_j}{\sum_{j=1}^{m} d_j}, j = 1,2,\ldots,m. \quad (12)$$

Step 5. Constructing a square matrix.

The highest values from each column of the normalized data matrix are chosen to create this matrix, as shown below:

$$a_j = \max \tilde{x}_{ij} = a_{kij}, i = 1,2,\ldots,n, j = 1,2,\ldots,m. \quad (13)$$

The element a_{kij} represents the highest value of the criterion or the value in the j[th] column taken from the sample or row k_i. In order to form a square matrix with the $m \times m$ dimensions and $a_{ij} = a_{kij}$ and $a_{jj} = a_j$. Thus, the i[th] row of the square matrix will include the elements from row k_i of the normalized matrix.

Step 6. Constructing the lost impact matrix.

The square matrix of the lost impact for the criteria is created by using the square matrix from the previous step, as follows:

$$p_{ij} = \frac{a_{jj} - a_{ij}}{a_{ij}}, i, j = 1,2,\ldots,m, p_{ij} = 0, \quad (14)$$

where, p_{ij} denotes the loss of the relative impact of the j[th] criterion or variable when the i[th] criterion is selected as the optimal one.

Step 7. Computing the weight system matrix.

The square matrix of the weight system is generated based on the relative impact loss values, as shown below:

$$F = \begin{bmatrix} -\sum_{i=1}^{m} p_{im} & p_{12} & \cdots & p_{1m} \\ p_{21} & -\sum_{i=1}^{m} p_{i2} & \cdots & p_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ p_{m1} & p_{m2} & \cdots & -\sum_{i=1}^{m} p_{im} \end{bmatrix}. \tag{15}$$

Step 8. Determining the weight of each criterion using the CILOS method.

If the weight of each criterion or variable is considered equal to qj, these weights are obtained from the following equation:

$$F_q^T = 0, \tag{16}$$

where qT is the linear vector of weights (i.e., $q = [q_1, q_2, \dots, q_m]$). From the solution of *Eq. (9)*, the weights calculated by the CILOS method in such a way that $\sum_{j=1}^{m} q_j = 1$.

Step 9. Determining the weight of each criterion using the cumulative method.

Ultimately, the weight of each criterion is calculated by combining the weights obtained from the entropy method w_j and the CILOS method q_j using the following equation:

$$\omega_j = \frac{q_j w_j}{\sum_{j=1}^{m} q_j w_j}, \quad j = 1,2,\dots,m, \tag{17}$$

where ω_j is the final weight of the j^{th} criterion by the IDOCRIW method.

3.3 | Combined Compromise Solution Method

Combined Compromise Solution (CoCoSo) method aims to identify the most suitable alternative by merging concepts of compromised solutions, such as mean evaluation weighting and power weight aggregation. The step-by-step process of the CoCoSo method can be summarized as follows:

Step 1. Construct the decision matrix.

The initial step involves creating a decision matrix that contains the alternatives and the criteria. The matrix typically includes alternatives (rows) and criteria (columns). The performance of each alternative with respect to each criterion is recorded:

$$x = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{n1} & x_{2n} & \cdots & x_{nn} \end{bmatrix}, \tag{18}$$

where x_{ij} represents the performance of alternative i for criterion j.

Step 2. Normalize the decision matrix.

Each criterion can have different scales, so normalization is applied to bring all the criteria to a common scale. Normalization is done depending on whether the criterion is beneficial (higher values are better) or nonbeneficial (lower values are better). The normalized value is calculated as:

For beneficial criteria:

$$\acute{x}_{ij} = \frac{x_{ij}}{\max(x_{ij})}. \tag{19}$$

For nonbeneficial criteria:

$$\acute{x}_{ij} = \frac{\min(x_{ij})}{x_{ij}}. \tag{20}$$

Step 3. Determine the weighted normalized matrix.

Each criterion is assigned a weight based on its importance, usually obtained through expert judgment or another method. The normalized decision matrix is multiplied by these weights:

z_{ij} where w_j represents the weight of criterion j and z_{ij} is the weighted normalized value.

$$z_{ij} = w_j \times \acute{x}_{ij}. \tag{21}$$

Step 4. Compute the aggregated score for each alternative.

Two types of aggregation techniques are used in CoCoSo:

The sum of Weighted Normalized Values (Mean Evaluation Weighting):

$$\bar{S}_i = \sum_{j=1}^{n} z_{ij}. \tag{22}$$

This is the sum of the weighted normalized values for each alternative.

Product of powered weighted values (power weight aggregation):

$$\bar{P}_i = \left(\prod_{j=1}^{n} z_{ij}{}^{wj}\right)^{\frac{1}{2}}. \tag{23}$$

This formula applies power weight aggregation by multiplying the weighted values raised to the power of the criterion weight.

Step 5. Calculate the combined compromise score.

The final score for each alternative is calculated by combining the results of the two aggregation methods using a combination parameter (α):

$$\bar{Q}_i = \alpha.\bar{S}_i + (1-\alpha).\bar{P}_i. \tag{24}$$

Typically, $\alpha = 0.5$ is used, representing an equal weight for both aggregation techniques. The combined score reflects the performance of each alternative considering both mean and power weight aggregation approaches.

Step 6. Rank the alternatives.

Finally, the alternatives are ranked based on their compromise scores $\bar{Q}_i$. The alternative with the highest score is considered the best choice.

3.4 | The Proposed Framework

This study applies an equally weighted distribution to gauge the significance of expert opinions, treating all specialists as equally important, regardless of variations in expertise, experience, or the perceived value of their input. Essentially, each expert's opinion is given equal weight. This approach is appropriate when there is minimal variation between the specialists, and a democratic decision-making process is needed to balance and moderate their viewpoints. Additionally, it is recommended to use fuzzy numbers in MCDM methods to account for uncertainty in the evaluation process. In MCDM research, the integration of FUCOM,

IDOCRIW, and CoCoSo methods offers several distinct advantages for evaluating complex problems. The FUCOM is particularly valuable for determining the weights of the main criteria. One of the key advantages of FUCOM lies in its ability to ensure maximum consistency in pairwise comparisons, which minimizes errors in weighting the criteria. This method allows decision-makers to derive optimal weights for the main criteria by ensuring logical coherence across evaluations. The strength of FUCOM lies in its emphasis on consistency, which leads to more reliable and accurate decision-making processes. In scenarios where various main criteria carry different levels of importance, FUCOM provides a systematic approach to assign weights in a way that reflects the true relative importance of these criteria, ultimately enhancing the objectivity of the decision-making process.

The IDOCRIW method is used to determine the weights of sub-criteria. It is particularly effective in addressing situations where sub-criteria have varying degrees of significance. IDOCRIW integrates both subjective judgments from experts and objective data to assign weights to the sub-criteria, thus balancing the qualitative and quantitative aspects of decision-making. By improving the weight allocation of sub-criteria, IDOCRIW enhances the precision and robustness of the evaluation process. It also accounts for uncertainty and variability in expert opinions, offering a more nuanced and dynamic weighting approach, which is essential when dealing with complex decision environments.

Finally, the CoCoSo method is employed for the final ranking of solutions. CoCoSo is known for its ability to combine and synthesize different criteria and sub-criteria, offering a comprehensive ranking of alternatives. It operates by calculating a compromise solution, which balances between the optimality of solutions and the tradeoffs among criteria. CoCoSo not only takes into account the weights assigned to both main criteria and sub-criteria but also provides a flexible and adaptive approach to ranking, which makes it ideal for scenarios where multiple conflicting criteria need to be considered. The method's capability to generate a final ranking that reflects both the consistency of the criteria weights and the overall performance of alternatives makes it an essential tool in decision-making. In summary, the combination of FUCOM, IDOCRIW, and CoCoSo methods ensures a comprehensive and accurate decision-making framework, enabling decision-makers to assign proper weights to both criteria and sub-criteria and to derive an optimal solution ranking that is robust, consistent, and reflective of the complexity of the problem at hand. These methods together provide a structured approach to dealing with MCDM problems, especially in uncertain and complex decision-making environments. Additionally, to assess the reliability of the weighting results, a sensitivity analysis is conducted across various decision-making scenarios provided by experts (7 scenarios). To ensure the accuracy of the ranking outcomes, the results are compared and evaluated using multiple MCDM methods under fuzzy conditions.

4 | Finding

This study identifies the key factors that contribute to enhancing E-commerce trust in crowdfunding by integrating blockchain and edge computing. It focuses on security, transparency, efficiency, social trust, and technical capabilities as the main influencers of E-commerce trust in crowdfunding. By analyzing existing literature, the research identifies the most effective solutions for incorporating blockchain and edge computing in fostering E-commerce trust within crowdfunding. A practical case study from Iranian crowdfunding platforms is evaluated using MCDM methods, such as FUCOM, IDOCRIW, and CoCoSo techniques with fuzzy numbers. Additionally, sensitivity analysis and validation are performed using F-MARCOS, F-SECA, F-KEMIRA, and F-MABAC techniques.

4.1 | Identifying Indicators of E-commerce Trust in Crowdfunding

At this stage, the indicators are determined through a review of the research related to implementing E-commerce trust in crowdfunding. Additionally, the key indicators are validated by consulting with specialists from the research team *Table 2* states the indicators for reinforcement of E-commerce trust in crowdfunding based on the integration of blockchain and edge computing.

Table 2. Identified indicators of e-commerce trust in Crowdfunding.

Indicators	Sub-indicators
Security (C1)	Fraud prevention, data protection, identity verification, confidentiality, data integrity
Transparency (C2)	Clear communication, transaction transparency, financial reporting, project history, independent audits
Efficiency (C3)	System reliability, processing speed, cost reduction, energy consumption, ease of use
Social trust (C4)	Project credibility, user ratings, community support, team transparency, social interactions
Technical capabilities (C5)	Flexibility, technology support, updates and upgrades, scalability, interoperability

4.2 | Identification of Solutions Blockchain and Edge Computing in Fostering E-commerce Trust in Crowdfunding

This section outlines a selection of the most critical solutions identified through an analysis of relevant studies on the integration of blockchain and edge computing. *Table 3* highlights the proposed solutions for combining blockchain and edge computing to strengthen E-commerce trust in crowdfunding.

Table 3. Solutions for integration of blockchain and edge computing in crowdfunding.

Code	Solutions
S1	Using blockchain-backed smart contracts for secure transactions solution
S2	Implementing a decentralized user verification system
S3	Providing real-time analytics using edge computing for improved campaign tracking
S4	Implementing a blockchain-based auditing and monitoring system
S5	Providing smart algorithms for automated rating systems
S6	Enhanced security with blockchain and edge computing synergy
S7	Providing mechanism for reinforcement of social trust

4.3 | Determining the Importance of Indicators and Sub-Indicators

At this stage, the primary indicators are first weighted following the steps of the FUCOM technique. In this process, a decision matrix is created based on the opinions of experts, and the indicators are normalized according to the FUCOM method. Next, the deviation of each indicator and its correlation with other indicators are assessed, and the values are calculated.

These steps are then repeated to calculate the significance of the sub-indicators using the IDOCRIW method. The results of the final significance of the indicators and sub-indicators are shown in *Table 4*.

Table 4. The weight of the indicators and sub-indicators.

Indicators	Weight	Sub-indicators	Final Weight
I1	0.400	I11	0.069
		I12	0.057
		I13	0.041
		I14	0.029
		I15	0.025
I2	0.110	I21	0.059
		I22	0.028
		I23	0.032
		I24	0.028
		I25	0.021

Table 4. Continued.

Indicators	Weight	Sub-indicators	Final Weight
I3	0.315	I31	0.085
		I32	0.049
		I33	0.047
		I34	0.038
		I35	0.024
I4	0.117	I41	0.063
		I42	0.031
		I43	0.032
		I44	0.033
		I45	0.025
I5	0.102	I51	0.045
		I52	0.045
		I53	0.046
		I54	0.033
		I55	0.022

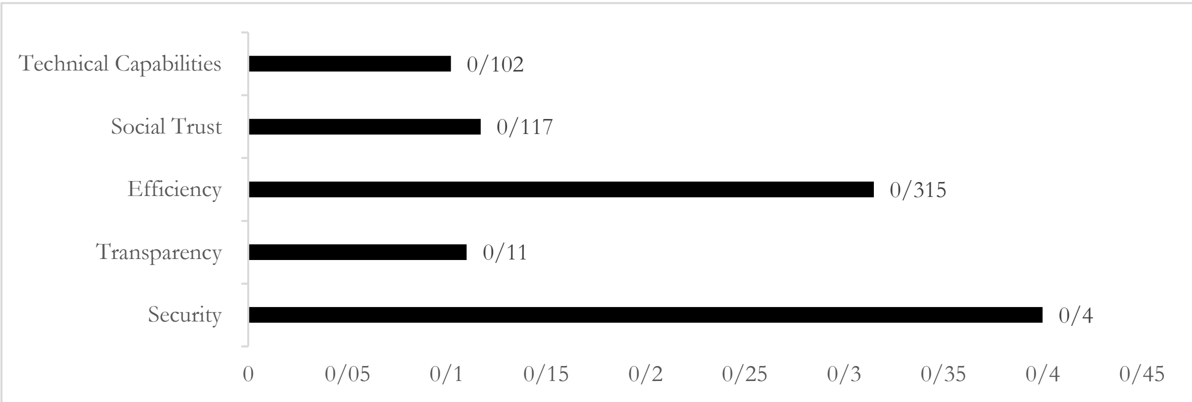

Fig. 2. Comparison of the weight of indices.

The study highlights five critical sub-indicators for integrating blockchain and edge computing in the reinforcement of E-commerce trust in crowdfunding: system reliability, fraud prevention, project credibility, transaction transparency, and data protection were identified as the most impactful. System reliability ensures consistent platform performance, while fraud prevention mechanisms are crucial for protecting users from potential threats. Project Credibility enhances trust in crowdfunding initiatives, transaction transparency builds confidence in financial exchanges, and data protection is vital for safeguarding user information.

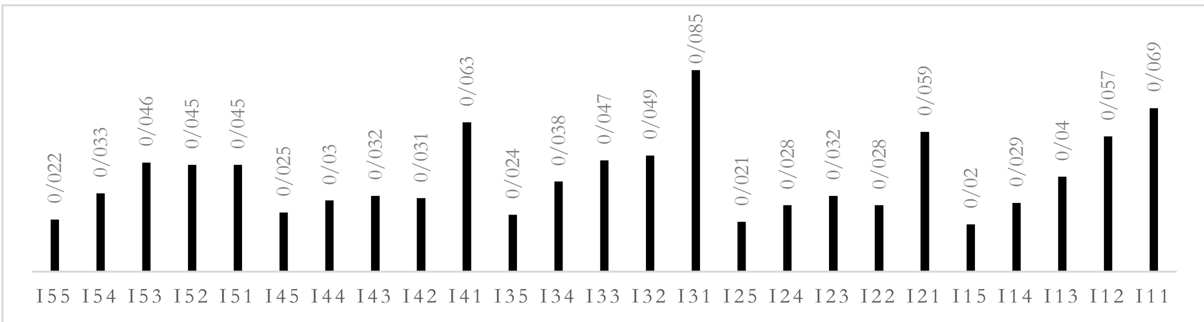

Fig. 3. Comparison of the weight of sub-indices.

4.4 | Evaluation of the Solution of Blockchain and Edge Computing in the Reinforcement of E-commerce Trust in Crowdfunding

This section evaluates the integration of blockchain and edge computing in enhancing trust in e-commerce crowdfunding based on experts' opinions. The preferences for each solution are determined according to specific indicators. The following solutions are analyzed and ranked using the F-CoCoSo method, with the results shown in *Table 5*. The evaluation reveals that the top-priority solutions for integrating blockchain and edge computing to strengthen trust in e-commerce crowdfunding are S4 (Implementing a Blockchain-Based Auditing and Monitoring System), S2 (Implementing a Decentralized User Verification System), and S6 (Enhanced Security with Blockchain and Edge Computing Synergy).

Table 5. The findings of solutions ranking.

Solutions	k_{ia}	k_{ib}	k_{ic}	$\tilde{k}_i$	$R(\tilde{k}_i)$	Rank
S1	0.080	0.100	0.120	0.870	2.314	6
S2	0.090	0.110	0.130	0.930	3.455	2
S3	0.070	0.120	0.110	0.900	3.164	4
S4	0.100	0.090	0.140	0.950	3.697	1
S5	0.060	0.100	0.100	0.850	2.913	5
S6	0.070	0.110	0.120	0.880	3.272	3
S7	0.050	0.090	0.100	0.820	2.514	7

4.5 | Sensitivity Analysis

In this stage, a thorough sensitivity analysis was conducted to evaluate how robust the findings are when varying the parameter α within the F-CoCoSo method. The variable α, a critical factor in MCDM, was systematically adjusted across a spectrum of values, ranging from 0 to 1. Each time α was modified, the assessment of the proposed solutions was recalculated to measure how changes in the decision-maker's preferences or weighting schemes might affect the ranking outcomes. This step is essential for ensuring the credibility of the results in diverse decision-making scenarios.

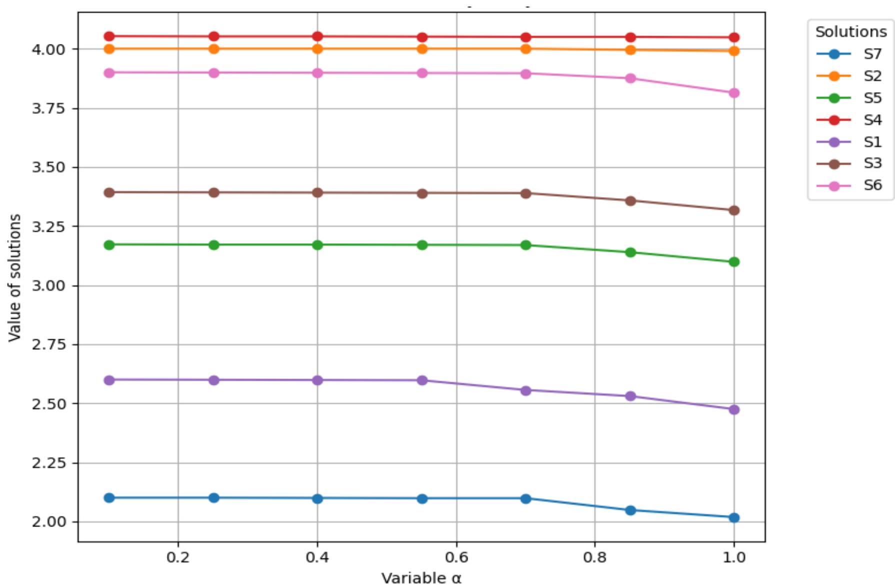

Fig. 4. The value sensitivity analysis.

The primary objective of this sensitivity analysis is to explore whether the specialists' opinions about the solutions might shift under different conditions or contexts. This process provides valuable insights into the stability of the model and its capacity to handle variability in human judgment. For example, in real-world situations, decision-makers may prioritize different aspects depending on evolving circumstances, such as market demands, technological advancements, or shifts in regulatory policies. Understanding how the model performs when these priorities shift is key to confirming the robustness of the recommended solutions.

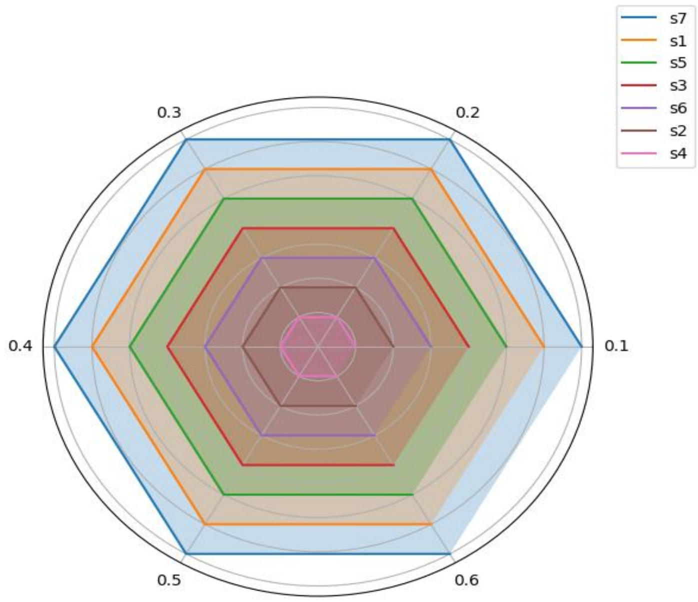

Fig. 5. the ranking sensitivity analysis.

The outcomes, which are visually depicted in *Figs. 4* and *5,* show that despite these deliberate changes to the variable α, the ranking of the solutions remains remarkably stable. The positions of the solutions do not alter significantly across different values of α, highlighting the model's resilience to changes in the decision-making criteria. While the scores of the individual solutions fluctuate slightly with adjustments in α, the variations are minor and, more importantly, do not affect the overall hierarchy of the solutions. This suggests that the results are not only reliable but also resistant to potential bias introduced by varying expert opinions.

4.5 | Comparative Analysis of the MCDM Approaches

To validate the findings, a detailed comparative analysis was conducted using hybrid MCDM techniques. This assessment was based on the weighting results derived from the FUCOM and IDOCRIW methods, ensuring a robust and reliable evaluation framework. The proposed solutions were systematically compared across several advanced MCDM methodologies, including F-MARCOS, F-SECA, F-KEMIRA, and F-MABAC. These methods provide diverse perspectives on solution ranking and prioritization. *Table 6* summarizes the comparative results, and *Fig. 6* visually presents the ranking of the proposed solutions.

Table 6. Comparative Analysis The MCDM Methods.

Solutions	F-CoCoSo		F-SECA		F-KEMIRA		F-MABAC		F-MARCOS	
	Value	Priority	Value	Priority	Value	Priority	Value	Priority	Value	Priority
S1	2.314	6	0.421	4	1.102	5	1.264	6	0.816	4
S2	3.455	2	0.463	2	1.228	2	1.347	2	0.831	2
S3	3.164	4	0.389	5	1.114	4	1.306	5	0.754	6
S4	3.697	1	0.478	1	1.325	1	1.425	1	0.987	1
S5	2.913	5	0.376	6	1.078	6	1.314	4	0.792	5
S6	3.272	3	0.448	3	1.202	3	1.326	3	0.824	3
S7	2.514	7	0.323	7	1.012	7	1.238	7	0.743	7

The analysis revealed a strong correlation between the results of the F-CoCoSo method and those obtained from the other MCDM techniques. Across all approaches, solutions S4, S2, and S6 consistently ranked as the most effective in enhancing E-commerce trust within crowdfunding platforms. This consistent ranking highlights the robustness and validity of the findings across various decision-making frameworks.

Solution S4 focuses on creating a transparent, immutable, and fully traceable audit trail using blockchain technology. Blockchain ensures that each transaction is recorded in a distributed ledger that is tamper-proof and verified in real time. This auditability is crucial for fostering trust in the platform, as users can independently verify the authenticity and legitimacy of every transaction. Additionally, real-time monitoring

adds an extra layer of transparency, allowing stakeholders to track activities as they occur. By eliminating the possibility of data manipulation or fraud, this solution significantly enhances the reliability and security of financial transactions and investments within crowdfunding ecosystems. As a result, trust among both investors and project initiators is greatly reinforced.

Solution S2 redefines the user verification process by removing the need for a centralized authority to validate user identities. This approach not only streamlines the verification process but also strengthens security by ensuring that personal data and user credentials remain encrypted and are only accessible through cryptographic keys. The decentralization eliminates single points of failure, reducing vulnerabilities to cyberattacks and identity fraud. In crowdfunding platforms, where trust between users and the platform is paramount, this method provides a high level of assurance regarding user authenticity. The reduction of reliance on centralized entities for user verification mitigates risks associated with data breaches and identity theft, thereby enhancing platform reliability and reinforcing trust in the system's security protocols.

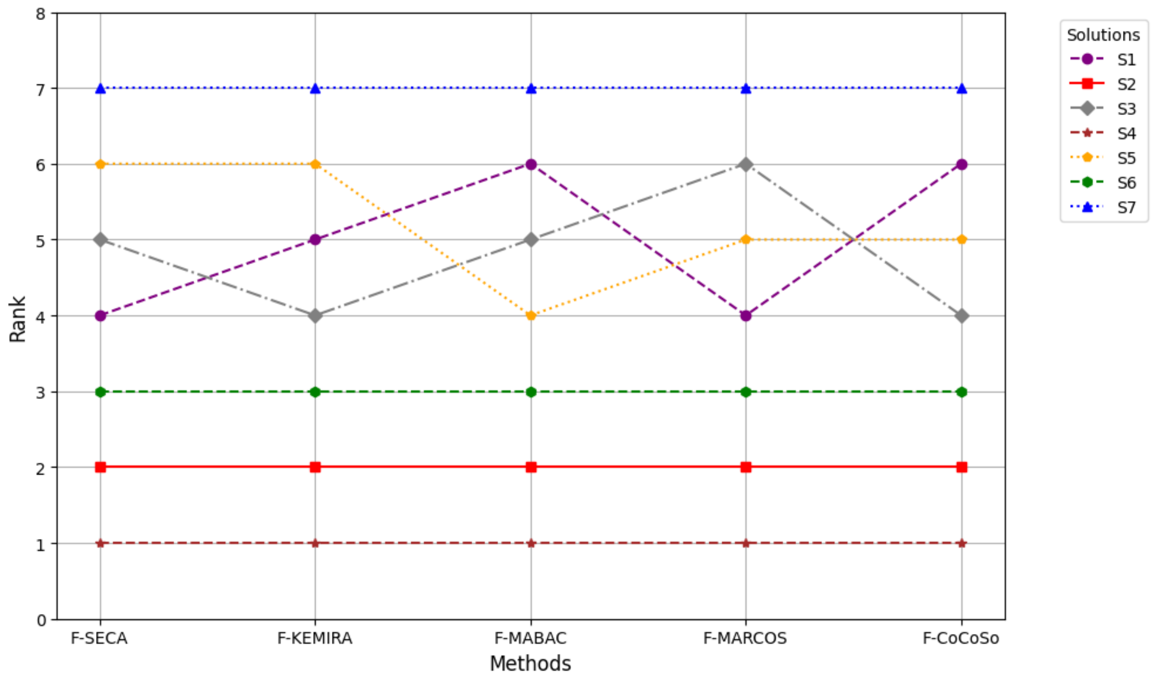

Fig. 6. Comparative analysis of the solutions.

Solution S6 combines the decentralized and immutable properties of blockchain with the computational efficiency of edge computing to enhance the overall security and performance of the crowdfunding platform. Blockchain ensures data integrity, as all transactions are securely stored across a distributed network, preventing unauthorized alterations. Meanwhile, edge computing reduces latency by processing data closer to the source, thus improving the platform's responsiveness. The integration of these two technologies creates a synergistic effect, wherein blockchain secures data at rest while edge computing safeguards data in transit and accelerates real-time decision-making processes. This combination not only improves operational efficiency but also enhances the platform's ability to handle large-scale crowdfunding activities without compromising security. By providing a faster and more secure environment, this solution significantly increases user confidence in the platform's ability to manage and protect their investments.

In summary, the integration of blockchain and edge computing within these solutions provides a comprehensive approach to reinforcing E-commerce trust in crowdfunding platforms. Solution S4's real-time auditing capabilities, Solution S2's decentralized user verification, and Solution S6's combined data security and processing speed all contribute to creating a more transparent, efficient, and secure crowdfunding environment. The consistency of these findings across multiple MCDM techniques further validates the effectiveness of these solutions in achieving the primary objective of enhancing user trust. Consequently,

these solutions represent a significant advancement toward the development of more trustworthy, reliable, and robust crowdfunding platforms, ultimately fostering sustainable growth in the E-commerce sector.

5 | Conclusion

This study advances the ongoing discussions on enhancing E-commerce trust in crowdfunding platforms by proposing an integrated framework that combines blockchain and edge computing. Through the application of MCDM methodologies, this research provides empirical support for current theoretical perspectives on trust within decentralized financial ecosystems. The findings hold both practical and theoretical significance, offering critical insights for future academic inquiry and real-world implementation.

The security dimension, particularly within financial and digital environments, remains a central theme in trust-building efforts. Previous studies, such as those by Zheng et al. [37] emphasized the importance of secure transaction mechanisms as a foundational element for gaining user trust. However, such solutions primarily relied on centralized systems or single-point security protocols. This study extends these insights by incorporating decentralized security through blockchain technology, paired with enhanced computational capabilities enabled by edge computing.

Blockchain's decentralized nature effectively removes single points of failure, ensuring cryptographic security and data integrity. The integration of edge computing addresses performance bottlenecks often encountered in blockchain applications, which typically suffer from latency issues when processing large-scale operations. Solution S6, which combines blockchain with edge computing, mitigates these challenges by distributing the computational load, enhancing both security and performance.

Additionally, the study identifies fraud prevention mechanisms as a critical sub-indicator of trust. Blockchain-based audit trails provide real-time, tamper-proof records of all transactions, preventing fraudulent activities. This feature has significant implications for eliminating fraudulent campaigns and bolstering project credibility—key challenges previously identified in crowdfunding research [34]. By demonstrating how immutable real-time audit trails improve user confidence in the integrity of crowdfunding platforms, this study enhances the understanding of security mechanisms within decentralized ecosystems.

Transparency has long been recognized as a key factor in building trust in E-commerce, especially in crowdfunding environments [57]. Traditional models of transparency, often reliant on periodic disclosures or user feedback, are prone to manipulation or delays. This study introduces Solution S4, a blockchain-based auditing system that offers real-time transparency, representing a significant advancement over existing practices.

The blockchain system enables continuous transaction monitoring, providing users with access to immutable records of all activities and mitigating the risks associated with information asymmetry—a frequent issue in crowdfunding platforms. This distributed trust environment allows users to verify transaction integrity without relying on a central authority. The F-CoCoSo analysis reinforces the significance of Solution S4, consistently ranking it among the most effective solutions for fostering trust. Moreover, edge computing enhances transparency by reducing latency in data processing, making information accessible almost instantaneously, and further addressing concerns regarding blockchain's transaction delays.

Efficiency, often considered a secondary concern in trust models, is redefined in this research as a primary factor directly linked to user trust. By processing data closer to the source, edge computing reduces the latency typically associated with traditional blockchain networks, which are often criticized for slow transaction processing due to the distributed ledger verification process. The combination of blockchain and edge computing (solution S6) creates a system that offers both faster transaction times and enhanced security, addressing two key challenges simultaneously.

This finding represents a significant progression from earlier approaches that treated security and performance as separate concerns. The FUCOM weighting method employed in this research underscores

the growing importance of performance in MCDM models, where efficiency plays a pivotal role in shaping user perceptions of platform reliability.

In the realm of social trust, crowdfunding platforms have traditionally relied on community engagement and reputation systems [34]. However, these mechanisms are vulnerable to bias and manipulation. This study introduces a novel approach to social trust through decentralized user verification (solution S2). By leveraging blockchain technology, user identities are authenticated without the need for a central authority, reducing the risks of fraudulent accounts and identity theft—two major concerns in traditional systems.

This decentralized method transforms social trust from being peer-driven to technology-driven. Unlike prior research, which focused on reputation-based trust, this study demonstrates how cryptographic verification enhances mutual trust between users and the platform by ensuring that each participant's identity is securely verified. This contributes to a shared sense of security within the crowdfunding community, thus improving the authenticity of interactions.

Moreover, this study addresses a gap in the literature by showing that scalability and trust can coexist within a single framework. Previous research often treated these factors separately [57], but the integration of blockchain and edge computing demonstrates that platforms can scale efficiently while maintaining high levels of security and transparency. Edge computing facilitates real-time decision-making and data processing at the network's edge, significantly improving system responsiveness. This capability is crucial for handling large transaction volumes, a common requirement for crowdfunding platforms, while ensuring the trust needed for user engagement.

The MCDM methodologies applied in this research—particularly F-MARCOS and F-MABAC—validate the critical role of technical scalability in building trust. The consistent ranking of Solutions S4, S2, and S6 across these methods underscores the importance of platforms being able to scale without sacrificing security or efficiency. This study offers a new theoretical framework where trust-building mechanisms are seamlessly integrated with scalable technological infrastructures, setting a path for future developments in digital trust frameworks.

In conclusion, this study provides a significant contribution to advancing trust in E-commerce crowdfunding platforms by leveraging blockchain and edge computing to address key issues like security, transparency, efficiency, and social trust. It introduces a comprehensive framework, validated through empirical analysis, that enables the development of platforms that are scalable, secure, and transparent. This dual integration offers decentralized systems capable of addressing both trust and scalability challenges effectively.

The study marks a shift from traditional reputation-based trust mechanisms to cryptographic verification, presenting a reliable, technology-driven alternative. By incorporating edge computing, the research enhances real-time data processing, demonstrating how performance and trust can be simultaneously improved—an approach that goes beyond previous studies, which treated these aspects in isolation.

Future research should focus on optimizing scalability for global crowdfunding platforms that handle larger transaction volumes. Addressing regulatory challenges is also essential, requiring further investigation into aligning decentralized trust mechanisms with existing legal frameworks. Additionally, validating the proposed solutions in different cultural and regulatory settings is crucial, as trust dynamics can vary significantly across regions. Further exploration of how technologies like AI and IoT could complement blockchain and edge computing may unlock additional advancements in trust and scalability.

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Conceptualization, Mehran Saeidi Aghdam, and Sherrie X.Y. Komiak; Methodology, Mehran Saeidi Aghdam, and Maghsoud Amiri; Software, Alireza Bahiraie; Validation, Maghsoud Amiri; Data maintenance, Alireza Bahiraie; Writing-creating the initial design, Sherrie X.Y. Komiak; Writing-reviewing and editing, Maghsoud Amiri, and Mehran Saeidi Aghdam; Visualization: Mehran Saeidi Aghdam, and Alireza Bahiraie; Monitoring, Maghsoud Amiri; Project management, Mehran Saeidi Aghdam, and Sherrie X.Y. Komiak; All authors have read and agreed to the published version of the manuscript.

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Data Availability

All data supporting the reported findings in this research paper are provided within the manuscript.

Conflicts of Interest

The authors declare that there is no conflict of interest concerning the reported research findings.

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